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THERMAL STORAGE DEVICE

FIELD OF THE INVENTION

The present invention relates to thermal storage devices and in particular to the off-peak provision of refrigeration for subsequent use. It has been developed primarily for use as a refrigeration device and will be described hereinafter with reference to this application.

BACKGROUND

The following discussion of the prior art is intended to present the invention in an appropriate technical context and allow its significance to be properly appreciated. Unless clearly indicated to the contrary, however, reference to any prior art in this specification should not be construed as an admission that such art is widely known or forms part of common general knowledge in the field.

It is known to freeze water and other suitable liquid media during periods of low thermal load and later to draw upon the resultant ice bank when the required loading and energy costs may be higher. This mechanism provides a low-cost means of cooling. In addition, the substantially constant temperature of the ice can be utilised to provide a constant process temperature, and the ice bank enables the system more readily to meet peak cooling demands.

One known form of thermal storage device employs a number of spaced grids of refrigerant pipes extending between inlet and outlet manifolds. These grids are closely packed within a water tank so that over a period of around eight hours, they freeze most of the water within the tank into a solid block of ice. When the process is reversed, water is passed through the tank around the periphery of the block, which progressively melts the ice and chills the water flowing around it.

These known devices suffer from various shortcomings. Because the ice block is initially one solid mass, only its outer surface is exposed to the water flow. This flow can also bypass the block by fast tracking to the tank outlet as the ice melts, thereby reducing the degree of heat transfer and hence the efficiency of the device. The melting can also occur in an irregular manner causing further inefficiency.

Attempts have been made to overcome this deficiency by promoting water circulation through agitation, for example by aeration or by paddles. However, both of these methods increase the complexity and therefore the manufacturing cost of the

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device, and also reduce its efficiency because of the additional energy consumption associated with the agitation mechanism itself..

Another disadvantage of prior art devices is that the spaced grids of refrigerant piping cannot easily be changed. Switching pipes may be necessary for repair but also for changing the pipe material to suit different refrigerants. For example, copper is unsuitable for use with ammonia.

It is an object of the present invention to overcome or ameliorate one or more of the disadvantages of the prior art, or at least to provide a useful alternative.

SUMMARY OF THE INVENTION AND OBJECT

According to a first aspect of the invention, there is provided a thermal storage device including:

a generally cylindrical tank including outer sidewalls adapted to contain a first fluid;

a heat exchange fluid inlet to said tank;

a heat exchange fluid outlet from said tank;

a refrigeration unit;

at least one hollow refrigeration evaporator coil in fluid communication with said refrigeration unit by means of refrigerant feed and extraction pipes, said coil being helically disposed within said tank for freezing the first fluid adjacent the coil, such that in use the frozen fluid and the sidewalls together define a substantially helical path to direct the flow of a heat exchange fluid from said inlet to said outlet; and

a generally cylindrical column removably mounted to the tank and extending coaxially through an interior region of the tank, the column defining an inner sidewall of the tank.

Preferably, the column supports the coil.

Preferably, the device includes valve means disposed selectively to introduce relatively hot fluid into the coil to rapidly heat an outer surface thereof, so as to crack and create fissures in the frozen fluid and thereby increase the rate of freezing of the first fluid. More preferably, the valve means include a reversing valve operable on the refrigerant feed pipe.

Preferably, the device further includes at least one sensor for detecting propagation of an interface between a frozen phase and surrounding liquid phase of the first fluid.

In a preferred embodiment, the heat exchange fluid has a lower freezing point than the first fluid.

According to a second aspect of the invention, there is provided a method of operating a device as defined above, including the steps of:

directing an evaporative fluid through the evaporator coil so as to reduce the temperature of an outer surface of the coil to a temperature less than or equal to the freezing point of the first fluid,

thereby causing said first fluid to freeze on the outer surface of the evaporator coil,

allowing sufficient time for an interface between solid and liquid phases of the first fluid to advance such that the frozen liquid and the sidewalls together define a substantially helical path; and

directing a heat exchange fluid to flow along said helical path such that the temperature of the heat exchange fluid progressively drops toward the temperature of the frozen first fluid.

Preferably, the method includes the further step of periodically injecting a hot fluid into the coil to crack and create fissures in the frozen fluid and thereby increase the rate of freezing of the first fluid.

Preferably, the hot fluid is selectively injected when required at a rate and temperature sufficient to fracture discrete blocks from the frozen fluid, and thereby significantly increase the exposed surface area of the frozen fluid.

Preferably also, the method includes the further step of recovering the heat extracted from said heat exchange fluid for use in other applications.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a sectional side elevation of a refrigeration device according to the invention;

Figure 2 is a sectional plan view taken on line 2-2 of Figure 1;

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Figure 3 is a sectional side elevation of another embodiment of the refrigeration device with a slightly changed evaporator coil disposition to ease manufacture;

Figure 4 is a schematic layout of a refrigeration circuit incorporating the refrigeration device, the circuit being configured to chill water to ice and recover waste heat; and

Figure 5 is a schematic layout of the device showing various control components.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Figures 1 to 3 of the drawings, the refrigeration device 1 includes a right circular cylindrical tank 2 having a central cylindrical column 3 defining an annular operative chamber 4 bounded by outer and inner sidewalls 5 and 6 respectively.

The tank is positioned vertically about an axis 7 and includes a heat exchange fluid inlet 8 adjacent the top of the tank and a corresponding outlet 9 at the base of the tank. In this embodiment, the heat exchange fluid is water.

The central column 3 supports a pair of refrigeration coils 10 and 11, each concentrically disposed within the tank in the form of a regular helix. The helices are of identical pitch in terms of revolutions per unit length, but of differing radii and are axially positioned such that in a section taken on a plane including the tank axis, at any given point the adjacent sections of the respective coils are always substantially disposed on a common radial line, as shown in Figure 3.

The coils 10 and 11 are each in fluid communication with a refrigeration unit 13 by means of a respective refrigerant feed pipe 13 and an extraction pipe 14.

In this embodiment, the coils are horizontally spaced in section as illustrated. In alternative embodiments where only a single refrigerant coil is used or where two or more coils are provided but are not horizontally aligned, the invention will operate, but may do so less efficiently.

Agitation means in the form of an axially extending perforate tube 15 is mounted within the tank 2. The tube includes an array of axially spaced nozzles 16 for injecting material into the water to increase its flow rate and turbulence. In this embodiment, the nozzles take the form of apertures in the tube. The increased

agitation has the effect of reducing the effective freezing point of the water, thereby allowing its temperature to drop to below 0°C without forming ice. The injection may be powered from the supply water or using a separate pump.

A typical refrigeration circuit including a refrigeration device as described above is illustrated in Figure 4. The circuit includes a compressor 17, suction accumulation vessel 18, oil trap 19, condenser 20, thermostatic expansion valve 21 and the evaporator coils 11 which are immersed in the thermal storage tank 2. The thermostatic expansion valve is typically controlled by sensing the exit temperature of the refrigerant from the evaporator tube by means of a sensor 22. The thermostatic expansion valve controls the ice temperature, which is typically set at -10°C.

A typical control system for the device is illustrated in Figure 5 and includes several features in common with the refrigeration circuit, with corresponding reference numerals indicating like features.

The control system includes valve means 23 disposed selectively to introduce relatively hot fluid into the coil to rapidly heat an outer surface thereof, so as to crack and create fissures in said frozen fluid and thereby increase the rate of freezing of the first fluid. The valve means including a reversing valve 23 operable on the refrigerant feed pipe.

An electronic expansion valve 21 is operable on the refrigerant feed pipe for metering the evaporation of refrigerant gas within the evaporation coil. A pair of sensors 24 and 25 are positioned to detect propagation of an interface between a frozen phase and surrounding liquid phase of the first fluid between respective predetermined maximum and minimum positions in response to progressive freezing of the first fluid.

The control system further includes a temperature sensor 26 on the outlet and a temperature sensor 27 on the inlet. The outlet sensor 26 ensures that water is supplied at the design temperature. The inlet sensor 27 detects the return temperature of the heat exchange fluid entering the tank. A timer 28 is included to activate the refrigeration unit in off-peak periods. A manual override mechanism (not shown) is also provided to permit activation of the refrigeration unit outside of off-peak periods.

An inlet pressure sensor 29 detects pressure in the inlet and an outlet pressure sensor 30 detects pressure in the outlet. The inlet and outlet pressure sensors, among

other functions, detect a build-up of pressure resulting from a blockage in the system. High and low pressure sensors 31 and 32 ensure that the refrigeration compressor operates within safe working limits. A condenser fan controller 33 controls condenser fans (not shown) and optimises condensation.

A solenoid valve 34 is positioned to close the refrigeration circuit and also to allow multiple thermal storage devices to be connected to a single refrigeration unit. A pump 35 is provided and is responsive to a speed controller 36. The speed controller adjusts the pump speed based on the temperature sensed by the inlet temperature sensor 27. Where this temperature is higher than the optimal level, the pump speed in increased accordingly.

Electronic control means 37, including a microprocessor 38, control the operation of the device in response to adjustable set-points and predetermined system parameters including outputs from the various sensors described above.

The controller is adapted for remote monitoring, supervision and adjustment of various system parameters. The remote monitoring may be achieved through a modem and phone line, the Internet, or wireless devices such as GSM phones.

It will be appreciated that some or all of the control devices may be used, depending on the particular application. For example, in more cost sensitive market segments, or where maximum efficiency is of secondary importance, the condenser fan controller 33 and electronic expansion valve 21 may be omitted.

In use, the tank is filled almost completely with water and the refrigeration coils are operated as an evaporator to freeze the adjacent water. As this freezing process continues, the growing ice helices bridge the gap between the refrigeration coils and coalesce into a single ice helix.

The coils are positioned with respect to the tank sidewalls such that the freezing process can be permitted to continue until the ice helix touches or almost touches one or both of the inner and outer sidewalls. This stage is determined by the sensor 66, which detects the maximum extent of ice growth. The sensor may, for example, detect this stage through changes in resistance between the liquid and solid phases.

The over freezing of the ice mass may also be detected by the placement of thermocouples in areas where the ice mass is to stop forming. Once the temperature

of these thermocouples falls below freezing point, the ice mass has progressed to its design limit and the refrigeration plant is shut down.

It has been found that if the thermocouples are repetitively frozen in the ice mass, they may become damaged and unreliable. This defect has been ameliorated by placing the thermocouples 39 in a metal tube 40 which is partially filled with a low freezing point liquid such as ethylene glycol to effect heat transfer to the thermocouples, thus enabling the thermocouples to sense temperatures below the freezing point of water without being subjected to the stress of being embedded in a frozen fluid.

The second sensor 25, which detects minimum extent of ice growth, ensures that a sufficient amount of ice is present to provide output water at the design temperature.

During the freezing of the ice helix, the ice formed around the helical evaporator coils increases in thickness and forms and insulation barrier to the further transfer of heat from the water in the tank to the evaporator coils thus slowing down the rate of ice growth. It has been found that if the evaporator coils are suddenly heated, the ice growth on the coils cracks, creating water paths through fissures in the ice to the evaporator coils and thus improving heat transfer and allowing more rapid growth of the ice layer around the coils.

With sufficient heat, it has also been found that discrete blocks of cracked ice can be broken away from the ice helices entirely so as to float freely in the tank, thereby further increasing the rate of ice formation on the coils, as well as increasing the total effective surface area of ice available for heat transfer.

Referring to Figure 4, the sudden introduction of heat into the evaporator coils is accomplished by means of hot gas injection from the refrigeration compressor 17. The injection is controlled by opening the reversing valve 23 on the refrigerant feed pipe 13 for a short period of time, thereby very rapidly raising the temperatures of the coils.

The hot gas injection may be controlled on a time basis throughout the freezing cycle or alternatively by means of sensors that detect the rate of ice build up or heat removal from the chilled water. In one embodiment, the sensor is a monitor on the refrigeration circuit that measures the rate of heat rejection at the condenser.

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The heat rejected at the condenser may be recovered in order to heat water for other uses within the establishment where the thermal storage device is installed. This is accomplished by using the heat exchanger 41 as a condenser for the refrigeration unit. The water to be heated enters the heat exchanger through the inlet 42 and leaves through the outlet 43.

The flexibility of the refrigeration circuit may be improved by the addition of three way valves 44 to provide for use of a regular air cooled condenser 20 in the form of a cooling tower. Alternatively, the hot water heat exchanger may be used as a condenser. This may be particularly advantageous where the temperature of the water being heated for other uses rises to a level at which the efficiency of the refrigeration unit is adversely affected.

Once the ice helix has been formed, the thermal storage tank is ready for use as a chiller by passing water through the tank from the inlet 8 to the outlet 9. The ice helix, together with the tank sidewalls, defines a substantially helical path for the water as it passes through the tank. This path is well defined and free-flowing to reduce the tendency of the water to by-pass the helix adjacent the tank sidewalls.

It is also apparent that the water is in constant heat exchange contact with the ice over a distance much greater than the length of the tank. The actual contact length is dependent on the size of the tank and the pitch of the coils. The pitch is approximately 12° in this embodiment and on that basis, a tank of 1.9 metres in length produces approximately 44 metres of helical path.

Water flow along the helix is promoted by an appropriately directed inlet 8 and outlet 9. Because of the substantially constant temperature of the ice, provided the water flow is not excessive, chilled water can be output at a substantially constant depressed temperature of around 0.5°C.

The water temperature may be further depressed to below 0°C by adding ethylene glycol to the chilled water supply to depress the freezing temperature of the chilled water below 0°C.

The tank may be formed of any suitable material such as polyethylene. The central column in the preferred embodiment is formed of polyvinylchloride piping and serves to support the refrigerant coil by means of a plurality of copper brackets 46. The tank includes a removable lid 47 to permit easy access to the helical coils, which

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can be removed integrally with the central column. This allows the refrigeration coils to be easily removed for inspection, cleaning or replacement. The lid, and supplementary insulation if required, effectively isolates the system from external environmental influences.

In other embodiments, the tank may be of non-circular cross-section with corresponding changes to the helix so that the ice can interact efficiently with the adjacent sidewalls. The central column can also be omitted, though with an increased tendency for water by-passing the ice helix. Particularly in this case, additional refrigeration coils may be added.

The tank may also be operated in a horizontal configuration. This is less desirable because higher flow pressures are required to compensate for the loss of gravity feed. It is also more difficult to produce a complete ice helix since the tank must desirably be full of water in its horizontal configuration and this involves additional means to provide for expansion of the ice on freezing.

It will be appreciated that the thermal storage device described above is well adapted for use in many applications requiring chilled water. These include industrial and agricultural processes such as beverage chilling, air-conditioning and food processing. The unit may be used to replace air-conditioning cooling towers without the need for special chemicals to control legionella bacteria. For heating applications, the device may be operated in a reverse cycle mode. In this mode, the reversing valve 47 is opened and hot gas is injected into the coils for a time sufficient to heat the water in the tank to the desired temperature.

In terms of effectiveness, efficiency, size, reliability and overall performance, the invention provides both practical and commercially significant improvements over the prior art.

Although the invention has been described with reference to specific examples, it will be appreciated by those skilled in the art that it may be embodied in many other forms.